Part C: Electronics Cooling Methods in Industry

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13. Heat Sinks

13.1 Definition

Heat sinks are devices that enhance the heat dissipation from hot surfaces. It is high thermal conductivity materials that makes low impedance, are often used on circuit boards to reduce component operating temperatures by minimizing the component-to-sink temperature difference.
The heat sink also provides an effective path for transferring the generated heat to an adjoining assembly or to the environment.

13.2 Components of Heat Sinks

13.2.1 Heat Sinks (Without using Fins)

Conductively cooled circuit boards use either strips or plates fabricated from copper or aluminum to transfer the generated heat to the card interface. These heat sinks could be found in different methods:
1. Bonded to the board surface either beneath rows of similarly shaped components Figure 13.1 (a)
2. On the unpopulated opposite surface, Figure 13.1 (b)
3. Printed wiring boards with high generated thermal power densities may be fabricated using an aluminum plate integrally bonded between thin layers of copper clad circuit board material, Figure 13.1 (c). Components can be attached to this assembly using the techniques developed for any two-sided circuit boards. Higher packaging densities are achieved by bonding assembled component boards to each side of an aluminum plate. In this case, the heat sink must transfer the heat generated by both assemblies

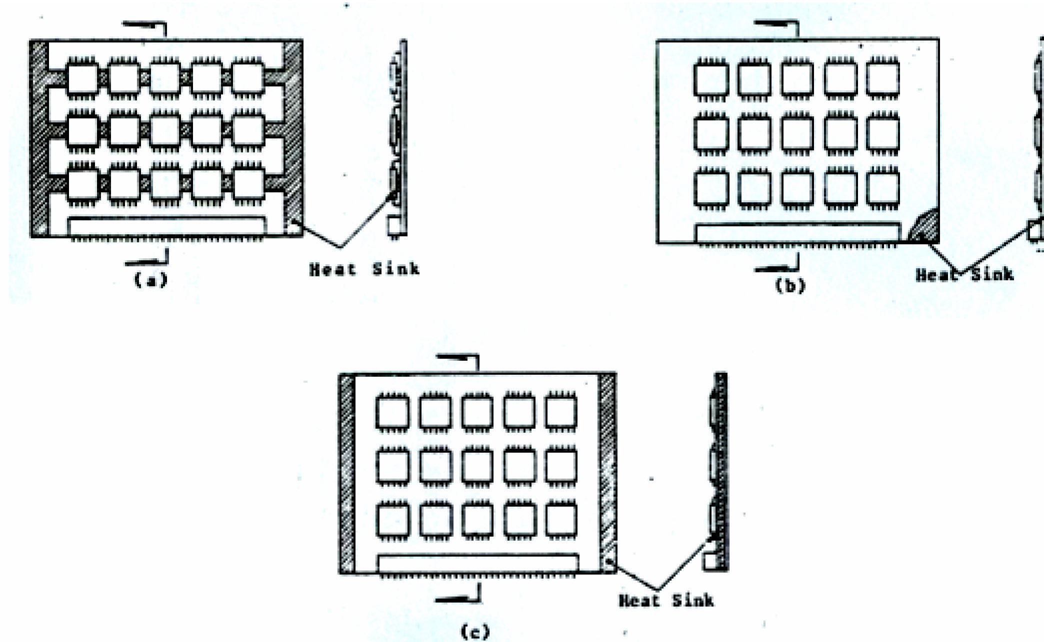


Figure 13.1 Different methods of low impendence material "heat sinks"

Built-up assemblies consisting of copper or aluminum and epoxy glass fiberboard may distort or warp when the equipment is operated. Changes in temperature may cause severe stresses in the attaching media because copper and aluminum experience about twice the expansion of the epoxy glass material. These effects can be reduced by the use of symmetrical sections with equal thicknesses of epoxy glass on each side of the metal center. Thermally induced distortion of nonsymmetrical assemblies can be

minimized by fabricating them at a temperature approximately midway between their expected high (operating) and low (storage or transport) service temperatures.

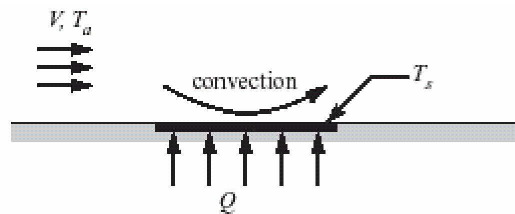
13.2.2 Heat Sinks (With Extended Surfaces "Fins")

We can more increase the effectiveness of the heat sink by installed local heat transfer enhancement devices "extended surfaces or fins" to increasing the convective surface area of the heat sink.

Principle of operation

For a given Q, A_s, V, and T_a, the convective heat transfer rate on the fluid side of the surface determines T_s

Increase the effective area for convection by adding fins.



$$T_s = T_a + \frac{Q}{hA_s}$$

Where h_{eff} is the effective heat transfer coefficient for the fin and exposed surface, and A_{eff} is the effective area.

From two pervious cases, we can deduce:

- Adding a single fin increases A_{eff}, and thereby decreases T_s.
- Increasing the number of fins will change the heat transfer coefficient.

Besides adding fins the effective heat transfer coefficient could be increased by using fans mounted to extended surfaces as shown in Figure13.2 and hence the surface temperature could be more reduced and the rate of heat dissipation also increased.

Figure13.2 Fans using with heat sinks

Fin Performance

The performance of the fin affected by fin configuration, the air velocity, number of fins and fin materials but the most important parameter is the air velocity, Figure 13.3 show the heat sink (fins) performance of the pin fins attached by thermal tape.

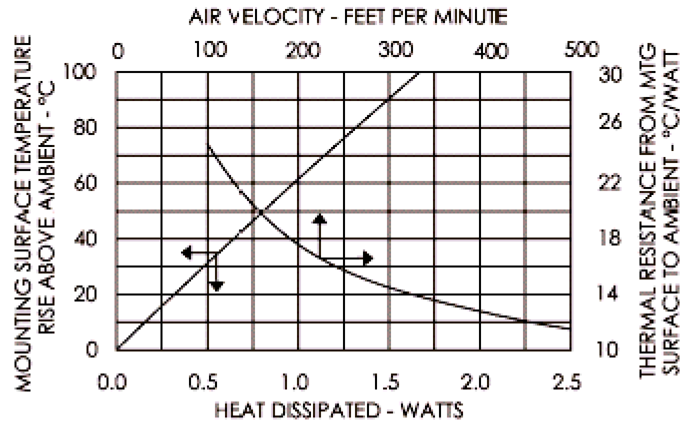


Figure 13.3 Fins performance of pin fins attached by thermal tape

Case study

1. Show that various shapes of extended surfaces (Fins) using in electronic cooling.
2. Find experimentally the relation between the thermal resistance and both heat input and number of fins.
3. Show the effect of fan speed on the heat sink's (Fins) heat input, base temperature and finally the thermal resistance.

13.3 Cold Plates

High power electronic components or high heat density assemblies that result from miniaturization often require a more effective heat removal system than is offered by conductive heat sinks. The cold plate combines the effects of a conductive heat sink with convection heat transfer to reduce the impedances between the generating heat sources and the thermal sink. Because of the availability of air from either the surrounding environment or conditioned sources, so that it is commonly used. The cold plate isolates the cooling air from the circuits and components being cooled, avoiding difficulties attributed to entrained moisture and airborne contaminants.

The configuration and design of the cold plate may take on different forms and sizes depending on equipment packaging and thermal requirements. Specific flow paths depend on the nature and distribution of the assemblies requiring cooling, intermediate conductive paths between the thermal sources and the cold plate interface, and equipment structural, and maintenance consideration.

Cold plates are usually fabricated from aluminum as welded or brazed assemblies. These assemblies can be used as chassis walls, Figure 13.4 (a) or for the indirect cooling of high powered electronic assemblies such as that illustrated in Figure 13.4 (b).Cold plates can also be integrated into the chassis design via the use of formed finned stock assembled into a prepared cavity, as shown in Figure 13.4 (c) Adhesives retain the finned stock, preventing flow short circuiting. The wall-to-air temperature difference along the flow path can be minimized by the selection of a suitable fin density. Higher fin densities also increase the resistance to flow which may impact on the selection of increase the resistance to flow which may impact on the selection of a fan or otherwise constrain the application of the equipment.

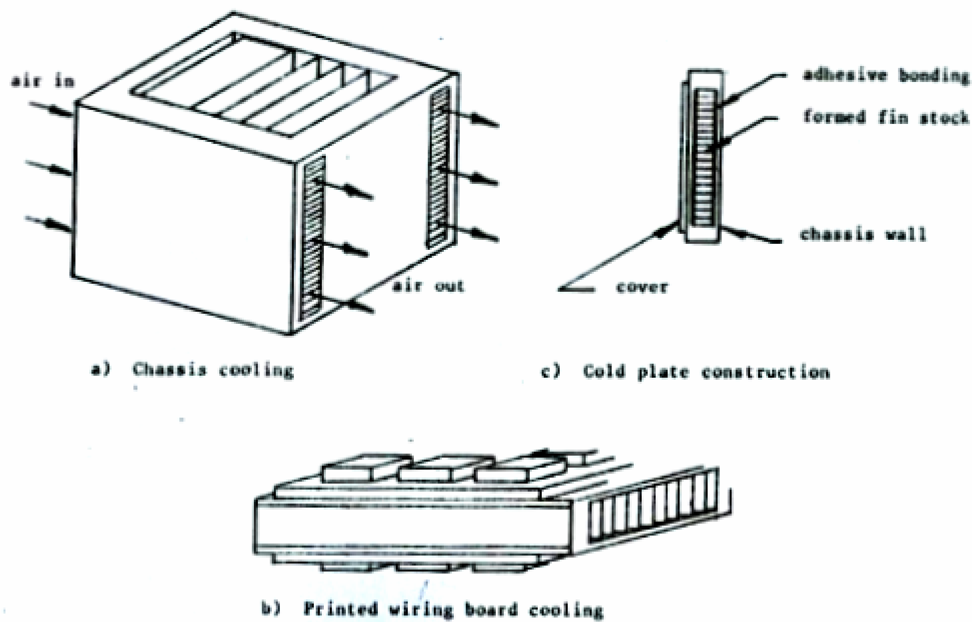


Figure 13.4 Cold plate configurations

Cold plates equipped with heat pipes as possible which will also reduce temperature gradients within the cold plate, developing a uniform temperature sink for attached assemblies.
Hardware design using cold plate techniques achieves an orderly arrangement of conductive heat transfer paths and air flow paths. Components or assemblies with high heat generation should be located either close to the cold plate wall or the coolant inlet.

13.4 Heat Sink attachment and Thermal Interface Effects on Production Assembly and Repair

Today's market offers many heat sink attachment and thermal interface options. Your design decisions usually aim to optimize product performance at minimum cost. Secondary effects not always sufficiently considered, significantly impact production cost, delivery performance, and reliability. These effects stem from the impact of the heat sink attachment design on the product assembly and disassembly processes. A product designed for easy assembly will have more consistent quality, reliability, and delivery performance. The ability to remove and replace the heat sink without damaging the device, the heat sink, or neighboring devices can also improve production parameters. To optimize assembly and repair processes consider these questions:

- Is the heat sink easily removable for repair?
- How many different parts and materials are needed to install the heat sink onto the board?
- Will personnel be exposed to any chemicals during installation or cleanup?
- Are specialized tools or equipment required?
- How sensitive is the assembly process to surface flatness or contamination?
- Will waste material for disposal be generated by the process or during cleanup?
- Will removal cause damage?
- Are attachment reliability and thermal performance sensitive to assembly techniques that may be inconsistent among assemblers?

13.4.1 Mechanical Attachment

Mechanical attachment generally consists of screws or clips that affix the heat sink directly to the device

or to the PCB. The issues to consider here are the interface between the heat sink and the device, the number and type of parts needed, and the stresses imparted to the PCB and the device. A thermal interface material is often needed to reduce contact resistance at the interface. This interface material may be applied during board assembly (usually the case with thermal grease) or it may be pre-applied by the heat sink vendor as a dry material. Assembly and repair operations will usually benefit from a dry pre-applied interface material. This reduces assembly time and eliminates cleanup and re-application of grease and exposure to chemicals in case of repairs. The pre-applied material will usually give more predictable and consistent thermal performance because the application thickness and coverage area are well controlled.

When designing the fastening system, consider the number and type of fasteners as well as the effect on the device and the PCB of the forces imparted by the hardware. Screws and clips generally permit the heat sink to be installed and removed without damage. Clips also generally accomplish the installation with the fewest parts. When designing for adequate contact pressure, consider the effect of the hardware on the devices and the PCB. High contact pressure designs can impart substantial camber to the PCB. Depending on the complexity of the design, a mechanically attached heat sink is often the easiest type to remove and replace for repair. In particular, designs that clip the heat sink directly to the device are simpler to replace without damage to the device, the board, or the heat sink.

13.4.2 Adhesive Attachment

Adhesive attachment is accomplished with double-sided tapes or dispensed adhesives such as epoxies. The advantages can be significant in the assembly process; however there are some drawbacks to repair. Adhesive tapes offer many design and assembly advantages. Tapes can be pre-applied to the heat sink for simple "peel and stick" assembly with little waste generation or chemical exposure. The attachment and thermal interface are combined in a single material. Also camber-inducing stress on the PCB is minimized.

One concern with adhesive tape attachment is that interface resistance and attachment reliability may be affected by surface flatness or contamination. Special tooling may be required to ensure proper bonding time and pressure is attained at assembly, particularly with delicate heat sinks. If the heat sink must be removed for repair, damage may occur and personnel may need chemicals or heat to remove adhesive residues.

The "wetness" of dispensed adhesives offers some advantages and disadvantages as compared with tapes. Employees will likely be exposed to the adhesive and cleanup chemicals when working with the dispensed material. Thermal performance may vary with adhesive thickness and coverage, thus tight process control may be required to ensure consistent results. Waste for disposal may be created from dispensing equipment cleanup. However, these materials tend to be more forgiving of surface flatness and roughness.

13.4.3 Repair

The cost and anticipated quality level of the components requiring heat sinks and the production volume and expected yield of the complete assemblies should influence the weight you place on repairability. A custom high power ASIC (application specific integrated circuit) may prompt a repair-friendly design. Such devices may be subject to running design changes requiring component replacements on the fly or on recalled or upgraded products. If a costly device is incorrectly installed it can be cost effective to remove, rework, and re-install that component provided the repair process is not too burdensome. An additional point is that quality improvement processes usually require FMA (failure mode analysis) of certain defective components. This analysis is sometimes difficult or impossible if the component is damaged during removal.

13.5 Specifying Filters for Air Forced Convection Cooling

Introduction

The importance and utility of air filters is often underestimated since it is typically an after-thought in the design cycle. Different filter designs and the selection process are reviewed to assist the design engineers in selecting a suitable filter for their specific application.

13.5.1 Filter Purpose

The two main reasons air filters are used in forced convection cooling systems are:

1. To remove particulate contaminants from the air
2. To create a laminar air flow

13.5.1.1 Particulate Contaminants

The importance of the removal of corrosive materials is well appreciated, but the reason for removing more benign ones (dust and dirt) may not be as obvious. These particles can accumulate on and in between electronic components, resulting in an electrical short and shrouding. The latter can alter air flow distribution and thus adversely affect thermal performance.

13.5.1.2 Laminar Air Flow

Flows with less turbulence are better in many applications because they have less friction and subsequently require less fan work. The latter is very desirable since fan generated acoustic noise is a point of contention in the forced convection cooling of electronic systems.

13.5.2 Operating Characteristics

There are a variety of materials used as filter media. These include coarse glass fibers, metallic wools, expanded metals and synthetic open cell foams. Each type of filter will have its own filter efficiency and pressure drop at a given air flow.

13.5.3 Filter Efficiency

Filter efficiency is the percentage measure of the air borne particulates that a filter is able to remove from the flow at a given velocity.
Hence, filters with higher efficiency have a larger pressure drop for a given air velocity. Also, the smaller particle a filter can collect, the greater the pressure drop across the filter for a given air velocity.

13.5.4 Pressure Drop

Filter pressure drop is a measure of the force required to move air through the filter at a given velocity. Each component in the system contributes a resistance to the air flow, which results in a pressure drop across itself. The total system resistance is the sum of all the pressure drops along the air flow path (including the filter).
The air filter pressure drop is a function of the velocity of the air and the filter type. Each filter will have a unique pressure versus air velocity characteristics. Performance curves showing these characteristics are used by designers during the filter selection process.

13.5.5 Filter Selection

Several specifications are required before an appropriate filter can be selected. A minimum list of specifications would be:

1. The available area for the filter
2. The system's volumetric flow rate
3. The maximum pressure drop allowed for the filter
4. Filter efficiency
5. Ability to create laminar air flow
6. Type of contaminants to be filtered

a). size of particles
b). corrosive or non-corrosive

Even more important than the filter selection is the orientation of the filter with respect to the fan or blower. The filter should be placed several inches away from the blower or fans via a mixing plenum. The filter should also be oriented perpendicular to the desired air flow direction, for example; as shown in the following Figure 13.5.

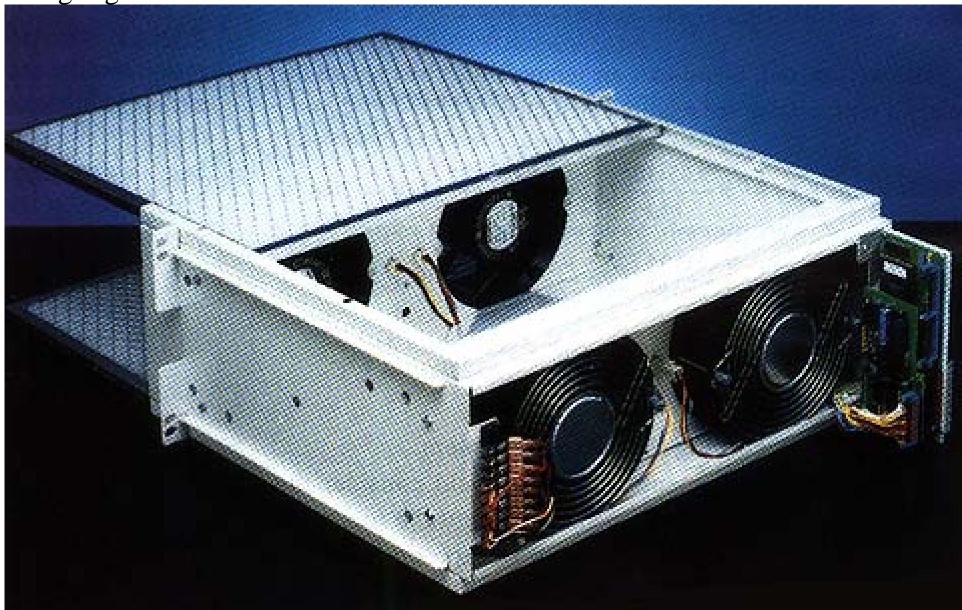


Figure 13.5 a custom cooling system for the telecommunications application, showing an example of air filters used to create a laminar air flow